Water Resources, Floods and Agro-Environment in Monsoon Asia

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Summary: Agricultural water use play important roles in the process itself as well as in the quantity aspect of the water circulation in the world. The visualization of this complicated process of agricultural water use, remained untouched, leads to the solution of the agro-environmental problems, such as foods, climate change, risks of floods and droughts, water footprint and so on. Therefore, this paper discusses how to cope with those problems mentioned above and the future challenges in researches of water resources related to agro-environments.

Keywords: Visualization, DWCM-AgWU, Agricultural Water Use, Climate Change, Water Footprint, Irrigation and Flood

1. Introduction

Rice cultivation of paddies in Monsoon Asian is not only an excellent form of agriculture offering high land productivity. It can also be seen as a sustainable and environmentally friendly economic activity that suits the climatic and topographical conditions of this region. This economic activity has continued to evolve for hundreds to thousands of years in various regions, as witnessed by archaeological traces of 7,000-year-old rice cultivation in China.

On the other hand, agricultural water use shares about 70% of the whole water use in Monsoon Asia as well as in the world. Monsoon Asia is categorized as the areas, where unique varieties coexist as i) distinct wet and dry seasons including high vulnerability on extremes (droughts and floods), and ii) various types of paddy irrigation and so on. In addition, agricultural practices are humane activities, so that it is important to model anthropogenic practices for agricultural water resources management.

This paper discusses the visualization process of the complicated agricultural water use in Monsoon Asia and shows how to cope with agro-environmental problems, caused by climate change (extremes), food problem, energy problem (hydro-power), catastrophic earthquakes through this visualization technics. Furthermore, challenging research topics in future are touched upon in agro-environmental fields related to water resources.

2. Method and Approach for the Visualization

Visualization processes have been realized by developing a hydrological, water allocation and water management models, namely the DWCM-AgWU (Distributed Water Circulation Model Incorporating Agricultural Water Use), [9, 12, and 18]. The key part of the modeling process is that it covers anthropogenic (human/ artificial /agricultural) activities as well as hydrological phenomena. A brief explanation follows in this section.

2.1 Targeted Basins for the Visualization

The model development began at the Mekong River Basin (800,000km^2) as a research target basin and it was extended to the Seki River Basin (1,140km^2) of Japan for its further development, applied to all of Japan.

2.2 Components in Runoff and Water Allocation & Management System

The DWCM-AgWU consists of, i) basin-wide runoff, parts of which are commonly obtained in any runoff model, ii) reservoir management in order to compare river discharge (available water) at division weir and water requirement in irrigated paddies and to release water for irrigation, iii) water delivery in irrigated paddies to decide intake, water allocation, infiltration, drainage.

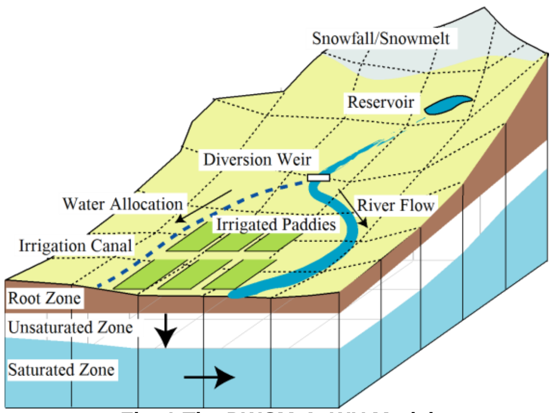

Fig. 1 The DWCM-AgWU Model

Figure 1 shows the model that allows us to divide a basin into cells and to find the water balance of each cell and the movement of water between cells connected with each other [12, 9]. The whole model consists of four (4) sub-models: the first one is an "Evapotranspiration Model" that works as the foundation of actual evapotranspiration estimation; the second one is a "Cropping Time and Area Model" that estimates the cropping progress of paddy fields varying depending on the paddy type and rainfall; the third one is a "Paddy Water Use Model" that evaluates the use and control of water; and the fourth one is a "Runoff Model" that represents the water circulation (Fig. 2). The model takes a variety of agricultural water use into consideration, so it allows us to forecast the cropping progress in accordance with annual water environments, and makes it easy to take measures against the effect of changes in land use because each cell has land use as an area percentage. In addition, the distributed runoff model can reproduce the irrigation status approximate to the real one and respond to the repeated use of irrigation water in a paddy field zone because it determines the actual intake by comparing it with the paddy water demand, facility capacity, and possible intake. Using this model allows us to estimate various data on agricultural water use at an arbitrary time and point, such as the cropping area of paddy fields, water intake, and soil's water content. Furthermore, we can evaluate and project the effect of various human activities (e.g. agricultural activity change and global warming) on the water circulation of the basin.

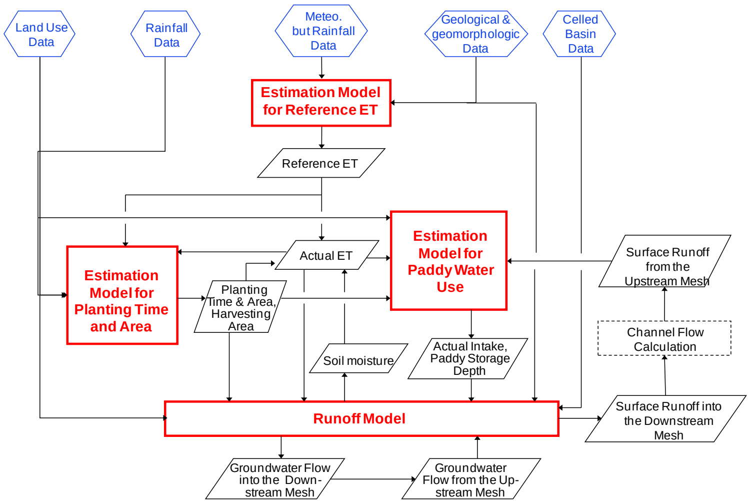

Fig. 2 Calculation algorism of water allocation and management model

2.3 Calculation algorism of the DWCM-AgWU

The runoff sub-model has completely distributed runoff structure in which cells connect with each other, which allows us to find out the water balance of each cell. We are able to estimate the runoff, groundwater movement rate, and soil's water content by inputting estimates from the other sub-models into this sub-model. The soil layer is classified into three types: a root zone having an effect on the evapotranspiration, a saturated zone having an impact on the groundwater movement rate, and an unsaturated zone connecting the previous two (Fig. 1). Note that the boundary between the saturated and unsaturated zones moves. Assuming that the thickness of the whole soil layer is constant in the cell, the daily water balance is found out for each layer. The cropping time and area forecast model estimates the planting start day of rice as well as its cropping and harvest areas, which vary depending on places and years, on a field type basis by receiving in-depth land use information about paddy fields and taking account of differences in field type and annual changes in cropping time. The yield reduction area due to water shortage is estimated by defining the actual evapotranspiration as an index. In addition, of all the input values to the agricultural water use model, the cropping area, possible intake, and actual evapotranspiration are estimated by the cropping time and area and runoff models.

2.4 Modeling of Release and Water Delivery System and its Verification

A reservoir like a dam or an irrigation pond is placed between two cells in the distributed runoff model. The runoff coming from the upstream cell is the reservoir inflow that is inputted into the dam control model. The reservoir release given by the model is the outflow from the upstream cell, which is inputted into the downstream cell. Water release for irrigation from the reservoir is given by using the gross water requirement derived from the paddy water use model. When the runoff (river discharge at the intake point if no water is released from the reservoir) from the downstream part of the reservoir reduces, resulting in the shortage of the necessary intake, supplementary water is released from the reservoir to compensate the shortage.

Water distribution and control model of a wide irrigation area is also developed and combined into the DWCM-AgWU. This is a model that forecasts the actual intake as a certain point and the water supply to a paddy field in an irrigation district. Irrigation water taken from the river is

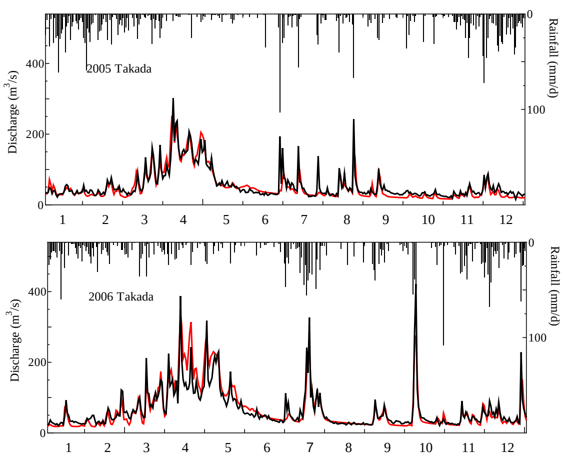

Fig. 3 Verification of the model

distributed to the district in needs.

Figure 3 represents the estimated results of surface flow at Takada Observation Station, the Seki River of Japan in 2005 and 2006. Relative errors between the observed and calculated discharges was 25 %, and it is concluded the estimation is quite good [17]. The same kind of verification was carried out in the Mekong River Basin to show the model's practical applicability, too.

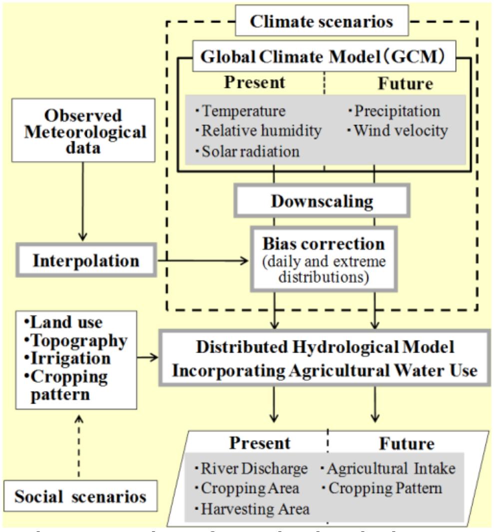

Fig. 4 Procedures for evaluating the impact of climate change

3. Agro-Environmental Problems Tackled in Water Resources Fields

The modeling of agricultural water use and/or water circulation turned out to be a good tool and it is regarded as a visualization process. This "visualization" is applied to many aspects, mentioned in details in the following sections. On the other hand, "Visualization" did not abruptly occur, but it has been involved in social conditions (problems) occasionally (5 applications) that reflect the times. Five applications to agro-environmental problems are reviewed here.

3.1 Climate Change Issues [Application 1]

The first application is climate change impact assessment to agricultural water use. Figure 4 shows the components of the method of evaluating climate change impacts to be described in this section and its procedures [4]. This evaluation system consists mainly of a down-scaler that increases the resolution of climate forecast scenarios, a bias corrector that corrects the difference (bias) between climate forecast and actual scenarios, and a distributed runoff model that provides concrete information about agricultural water use. We use the estimation results of the global climate model (GCM) to make climate forecast scenarios and to evaluate warming impacts. In this research, we input a scenario resulting from the down-scaler and bias corrector into the distributed runoff model, and compare the output with the actual one to evaluate the impact of climate change on agricultural water use. The following section describes the evaluation method component by component. The core part in this evaluation method is the DWCM-AgWU, that is, a modeling tool of visualization because it covers various kinds of agricultural water use as mentioned before.

The data produced by the ultra-high-resolution global atmosphere model (MRI-AGCM3.1S: Meteorological Research Institute-Atmospheric General Circulation Model 3.1 Super High Resolution) developed by Meteorological Research Institute through the Innovative Program of Climate Change Projection for the 21st Century were utilized to the Mekong River Basin, while those of MIROC3.2_HIRES (Space resolution: 1.1° mesh) under the SERES-A1B scenario was used for the assessment of all basins in Japan.

The method allows us quantitatively to estimate the future values, such as the river water intake, water supply to paddy fields, rice cropping time and area, and harvest time and area, according to a variety of social scenarios having an arbitrary period and in consideration of the impact of climate change. Figure 5 is one depiction of the future change of irrigation water in the Seki River Basin. It shows the ratio of irrigation water in future to the present, namely the rate of the end of the 21st Century (2081-2100) to the present (1981-2000) as a prediction during puddling periods. In this example, other assessments on extremes (irrigation and flood) were carried out to conclude that there was apprehension not to intake enough water to "water right amount" in future and that there would be skyrocket increase of annual maximum discharges [4].

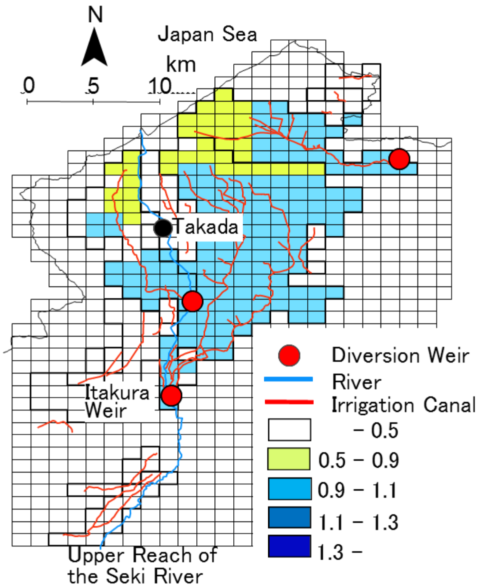

Fig. 5 Future change of irrigation water

3.2 Overseas Assistance in Agro-Environments [Application 2]

As the second application of the visualization, the developed model was used as overseas technical assistance tools. Target areas were the whole Mekong River Basin (taking the following basins as examples: Pursat River Basin (Cambodia) for Irrigation development in areas with scarce data [10], Nam Ngum River Basin (Lao PDR) for new water resources development for hydro-power generation [2], Xe Bang Fai River Basin (Lao PDR) for annually repeated flooding in paddies of the lower reaches [18], and the Mun-Chi River Basin (North East Thailand) for irrigation by large- & medium-scale dams [2, 3]) and the Chao Phraya River Basin (Thailand) for 2011 Flood and agricultural water use [19, 20].

Based on those examples, the most distinctive application is a new approach for generation of long-term continuous data in the areas with scarce data, especially in developing countries [10]. This example presents a "basin-scale irrigation planning" approach for use in areas of scarce hydro-meteorological data. The analysis presented here presents the results of the application of visualization to the Pursat River basin in Cambodia. Basic hydro-meteorological data are extremely scarce in these areas, partly as a result of the Cambodian civil war, and agriculture today is dependent mainly on rainwater. Hydro-meteorological and other data (topographic and land use) were simulated by using the procedure employed in climate change experiments by Masumoto (2010) and Kudo et al. (2012) and substituted for the observational data required for basin-scale irrigation planning. The input data for the model were the latest results from MRI projects (MRI-AGCM3.1S; 2007–2011) for the three 25-year spans mentioned above. Daily values for precipitation, maximum and minimum temperatures, and maximum wind speeds were extracted from the simulation results. These data and the simulated data were input to the DWCM-AgWU model for the Pursat River basin, the effects of climate change on the data were assessed, and the data for the three 25-year spans of data were generated. For example, simulated daily discharge at the Damnak Ampil weir on the Pursat River was obtained (Fig. 6).

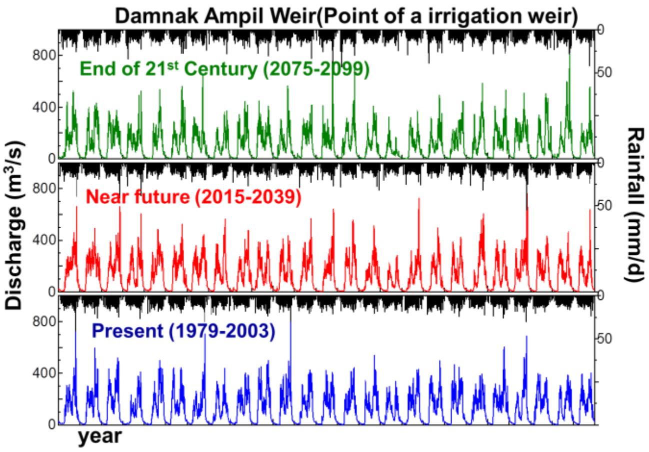

Fig. 6 Generation of quasi-observation data

This application showed that it is possible to model and use basic data as a substitute for observational data, so that effective irrigation plans can be prepared that detail the specific processes and procedures needed to materialize them.

3.3 Extension to Foods Issues [Application 3]

The model application has been extended from an initial basin, Seki River Basin, through all over Japan of 336 river basins with the accuracy of 1 to 5km cells in these days. In this process, the verification of the estimated values for the whole Japan was carried out to result in satisfactory results of the estimations, although some improvements remained needed for industrial and domestic sewage in urban-dominant basins. As a result, based on daily estimation by 5km cells, the information of rice planting in paddies turned out to be determined as cultivation day, irrigation amount, rainfall, soil moisture condition and so on. Furthermore, river flows in discharges of m^3/s were estimated at arbitrary points and times throughout all over the basins in Japan.

The process is directed to the socio-economic assessments on foods and agricultural water. The first direction is the development of the AFFEC Water-Food Model [1], in which hydrology and water resources fields were combined with various sectors as agronomy and socio-economics. This model lead to the impact analysis on foods in paddy-dominant areas, the proposal of counter-measures (land use change/development, breeding, irrigation, water management. etc.), and the evaluation of effects of mitigation & adaptation methods in "Food Politics." The second direction is the results of impact assessment in water resources were evaluated as the measurement of risks by a socio-economic model. Kunimitsu et al. [5] developed a model to analyze impact factors in productivity (TFP); parameter are the results estimated as paneled data (9 regions times 32 years). In addition, they introduced a Monte-Carlo simulation method by an Applied General Equilibrium Model (a prototype) [6].

3.4 Issues on Agricultural Water Right [Application 4]

As is mentioned before, agricultural water use in Monsoon Area is quite complicated. We have to notice that Dissimilarity between dry areas (field crop) and humid (paddy rice) areas in that the former practice use irrigated water fully, but the latter one carry out repeated use of irrigated water. In Monsoon Asia, especially in paddy irrigation, some of intake water from the river returns back to it, but it is difficult to grasp this ratio due to the complicity of agricultural water use even by the observation. Therefore, the fourth application is to make use of the visualization of water circulation, namely the model, in the determination of the river return ratio [14].

A case study used the averaged results of daily calculations estimated by the model for 33 years. The single process of rice cultivation involved flows of rainfall (888 mm during periods of irrigation) and irrigation water (957 mm during periods of irrigation) during the cropping period on average over the 33-year period. Other elements determined by DWCM-AgWU were evapotranspiration from agricultural areas (510 mm during irrigation periods) and infiltration into groundwater (623 mm during irrigation periods) on average for the 33-year period. The net ratio of irrigation water to total available water ($Q_{irrig}/[R + Q_{irrig}]$) was calculated to be 0.53 (0.74 if using the mean gross estimate) and the return ratio of irrigation water into the river system was 0.70, which shows that most of the irrigation water was returned to aquatic environments in the area and helped to regulate river flows.

3.5 ISO (Water Footprint) in Water Resources [Application 5]

The fifth application closely related to the former application presents a quantitative method for preparing a water footprint inventory by means of a hydrological model [11]. The method demonstrates the interaction of the water cycle with anthropogenic practices in agricultural water use and the recirculation use of water through returning flows at the basin scale. In addition, the effect on water availability is quantitatively calculated from land management practices that regulate river flows and recharge groundwater, such as those used in forestry, agriculture, and wetland conservation.

The calculated results were tabulated in Table 1. The production of brown rice in the region was 5.39 ton ha^{-1}. Although the apparent withdrawal of water for irrigation was 9,570 m^3 ha^{-1} (1.78 m^3 H_2Oe kg^{-1} brown rice yield), the real consumption was 5,100 m3 ha–1 (0.95 m^3 H_2Oe kg^{-1} brown rice yield), or 11,300 m^3 ha^{-1} (2.10 m^3 H_2Oe kg^{-1} brown rice yield). In addition, the groundwater recharge function of rice paddies in this particular example is 1.16 m^3 H_2Oe kg^{-1} brown rice yield at the basin level. In terms of the global average water availability index, this means that rice production results in a burden on freshwater resources equivalent to 2.10 m^3 of direct water use. The major factor contributing to the water consumption in this example is irrigation. The water availability footprint of rice cultivation is high because irrigation occurs in addition to rainfall input. It is important to note that agricultural water, especially for paddy cultivation, should be evaluated at the basin scale and the analysis should encompass the times when water demand is low and recognize the other functions of agricultural water use, such as the recycling of water for paddy cultivation, groundwater recharge, and reuse by river systems; that is, that not all water input to the irrigation area is lost from the basin

4. Proposals for the Future Subjects in Agro-Environment Researches

Challenging Researches in Future are listed as i) pure mechanism research in climate and irrigation (the longer observation is, the more chances to discover new phenomena), ii) notion of a basin as a change of the concept of basins (ex.: upland agriculture on the Kashima Plateau and aqua-researches), iii) oversea assistance in educational and technical assistance in Cambodia, iv) extreme events seen as 2011 Flood in Thailand (a seamless model combining irrigation and flood), related to exports of socio-infras, v) participatory disaster prevention planning of the practices for reducing floods by controlling irrigation gates, and so on. In this section, Nos. i, ii, and iv are selected as examples.

4.1 Mechanism Research Based on the Observation

In agro-environmental researches, continuous observation plays an important roles, and although it takes time, it actually resulted in a discovery of new facts [7, 12]. An observation at Chong Khneas of hydro-meteorological factors in Tonle Sap Lake has been continuing for more than 13 years [7].

4.2 Notion of the Basin

We found that the size of the groundwater catchment turned out to be larger than the surface one by 1.2 to 2.8 times [15, 16]. What is more, the cooperative project with a fishery research group made us notice that the new concept of wider watersheds including coastal waters should be considered.

4.3 Extreme Events

The occurrence of 2011 Flood in the Chao Phraya River of Thailand brought the necessity of the development of a seamless calculation model between irrigation and flood, which is regarded as an export of a rural infrastructure as a package [8, 19, 20].

3. Conclusions

This paper discussed how to cope with many agro-environmental problems by the visualization of agricultural water use and the future challenges in researches of water resources related to agro-environments.

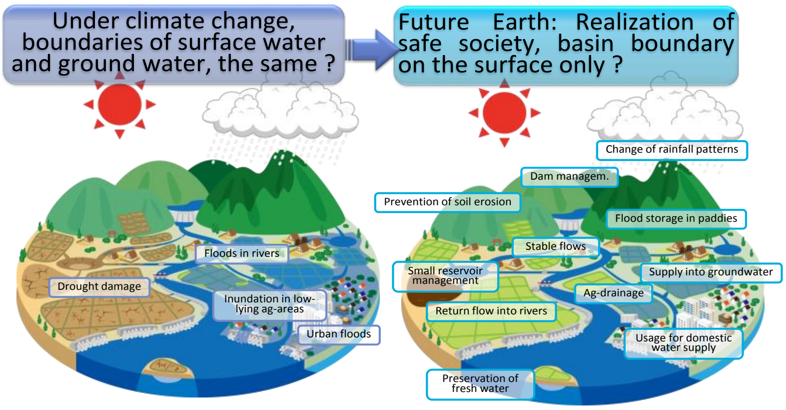

Fig. 7 Concept of the basin

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